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STUDY OF SEP SOLAR ARRAY MODIFICATIONS

FINAL REPORT

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ABSTRACT

A study was performed to assess the feasibility of modifying the Solar Electric Propulsion (SEP) 66 watt/kilogram, 12.5 kilowatt solar array blanket design to incorporate ultra-low mass blanket technology and to generate conceptual design data by modifying the SEP solar array design to a 17.5 kW power output. Five modified designs were developed, which substituted present SEP solar array design components with one or more of 50 micron thick solar cells, 75 micron cell coverglasses, and a different blanket substrate developed by GE. Additional design modifications required to accommodate the above are minor in nature. Certain technologies and fabrication processes require further development to demonstrate their readiness for use on flight hardware. These include welding of 50 micron cells, interconnect and substrate fabrication processes, and coverglass assembly methods.

A parametric analysis was performed to determine the solar array mast least weight and blanket tension required to maintain a minimum natural frequency of 0.04 Hz. The solar array wing assembly weights and power outputs were calculated, and preliminary cost estimates for flight hardware development, fabrication and qualification were made for each case studied.

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1.0 INTRODUCTION

During the last five years, Lockheed Missiles and Space Company, Inc. (LMSC) has developed a lightweight (66 W/kg) solar array design for application to Solar Electric Propulsion (SEP). This work has included development of needed new technologies and demonstration of the design through fabrication and testing of development hardware. More recently, JPL has funded GE to develop a design concept for a 200 W/kg solar array. Several proof-of-concept experiments were conducted on a design which used 50 μm solar cells and RTV 655 silicone as the adhesive between the cells and a 25 μm thick Kapton substrate. The objective of the present study is to determine the effort required to apply ultralow-mass features of the JPL/GE blanket design to the SEP fold-up solar array wing assembly.

Section 2.0 describes the 6 design cases studied. Section 3.0 details the design modifications made to the blanket and structures in incorporating the lighter-weight components. Section 4.0 discusses the technical developments required to prepare for fabrication of flight hardware, and Section 5.0 presents a preliminary cost estimate for development, fabrication and qualification of one or two wing assemblies. Section 6 completes the report, giving the study conclusions.

2.0 STUDY CASES

The study covered six cases as itemized in Figure 2-1. Case 1 is the present SEP baseline design. Cases 1-3 are for a 12.5 kW array, and Cases 4-6 for a 17.5 kW array. Case 4 is similar to Case 1 except for its higher power and its use of a thinner, 75 μm CMS cell coverglass. Cases 2, 3, 5 and 6 all use a 2 x 2 cm conventional solar cell 50 μm thick to reduce blanket weight. Of these, Cases 2 and 5 have a LMSC-type blanket substrate, while Cases 3 and 6 have a GE-type substrate. These design options are discussed further in the following paragraphs.

2.1 SEP Baseline Design

The SEP Solar Array Wing is shown in Figure 2-2. The arrangement of the solar cells on the array is given in Figure 2-3. Producing 12.5 kW, it has 125,460 solar cells 2 cm x 4 cm in size welded to copper interconnect circuitry contained in a Kapton/polyester laminate substrate. This solar array blanket is divided into 41 panels, connected by hinges, which fold up accordian-style into a container for storage during launch and reentry. When stowed a containment box cover compresses the array blanket to enable it to withstand launch and entry loads and vibration. Array extension/retraction and deployed stiffness are provided by a coilable lattice boom. A canister stores the coiled mast and contains the mechanisms for extending and retracting it.

The design requirements of the SEP array are summarized in Table 2-1. The most distinctive and demanding requirements are the following:

- Operation between 0.3 and 6.0 AU
- Operation in free space and in the earth's radiation environments with specified allowable degradation
- Power availability of 25 kW BOL and 21 kW EOL (1 AU conditions) while flying the missions specified in MSFC Solar Array Technology Development Program Control Document
- Weight limit of 380 Kg

CASE NO.	DESCRIPTION
1	SEP BASELINE DESIGN 2.00 x 4.044 CM x 200 μM CELLS 150 μM F.S. COVERS LMSC SUBSTRATE 12.5 kW
2	2.00 x 2.00 CM x 50 μM CELLS 75 μM CMS COVERS LMSC SUBSTRATE 12.5 kW
3	2.00 x 2.00 CM x 50 μM CELLS 75 μM CMS COVERS GE-TYPE SUBSTRATE 12.5 kW
4	2.00 x 4.044 CM x 200 μM CELLS 75 μM CMS COVERS LMSC SUBSTRATE 17.5 kW
5	2.00 x 2.00 CM x 50 μM CELLS 75 μM CMS COVERS LMSC SUBSTRATE 17.5 kW
6	2.00 x 2.00 CM x 50 μM CELLS 75 μM CMS COVERS GE SUBSTRATE 17.5 kW

Figure 2-1 Description of Cases

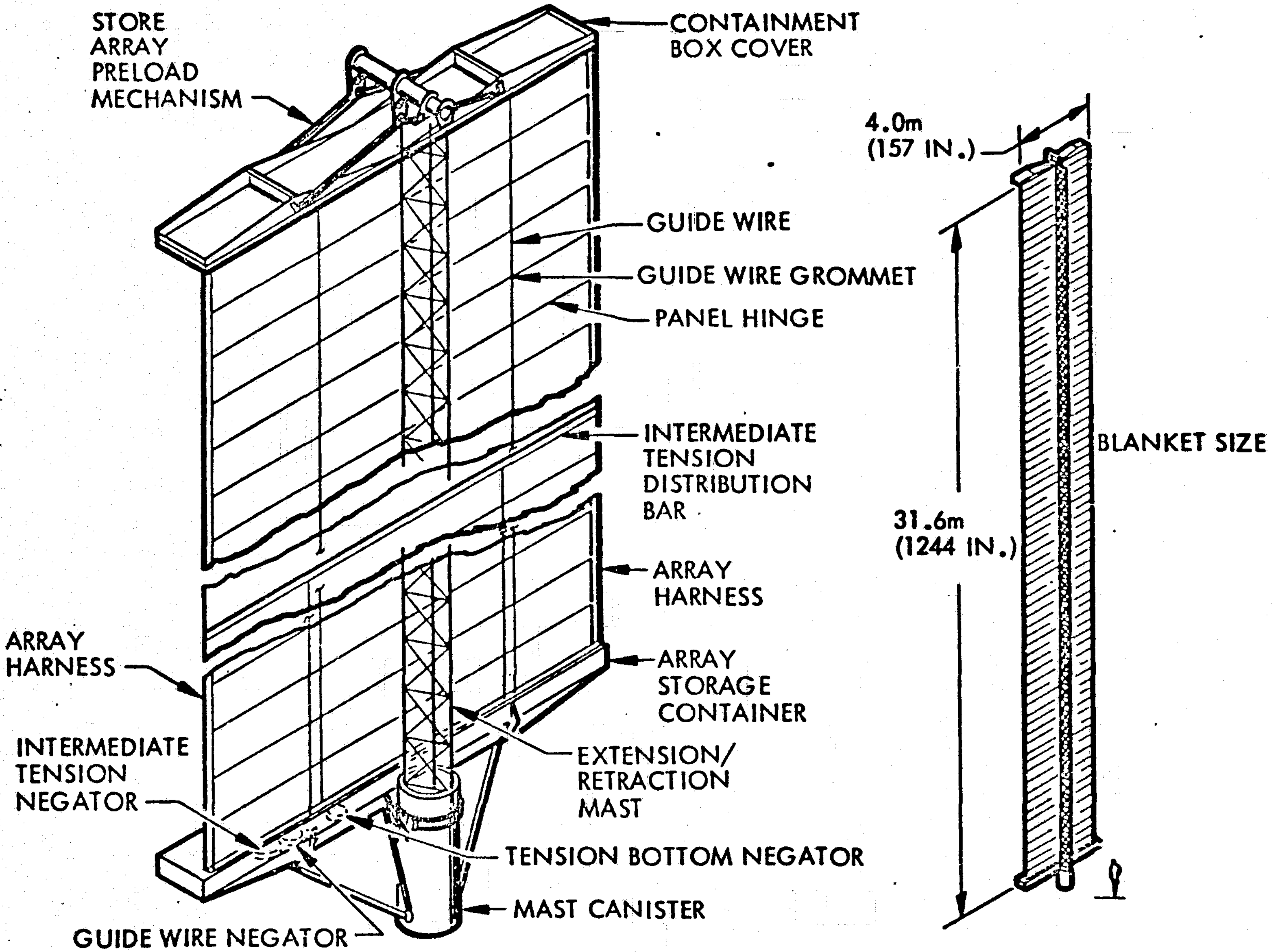


Figure 2-2 SEP Solar Array Wing

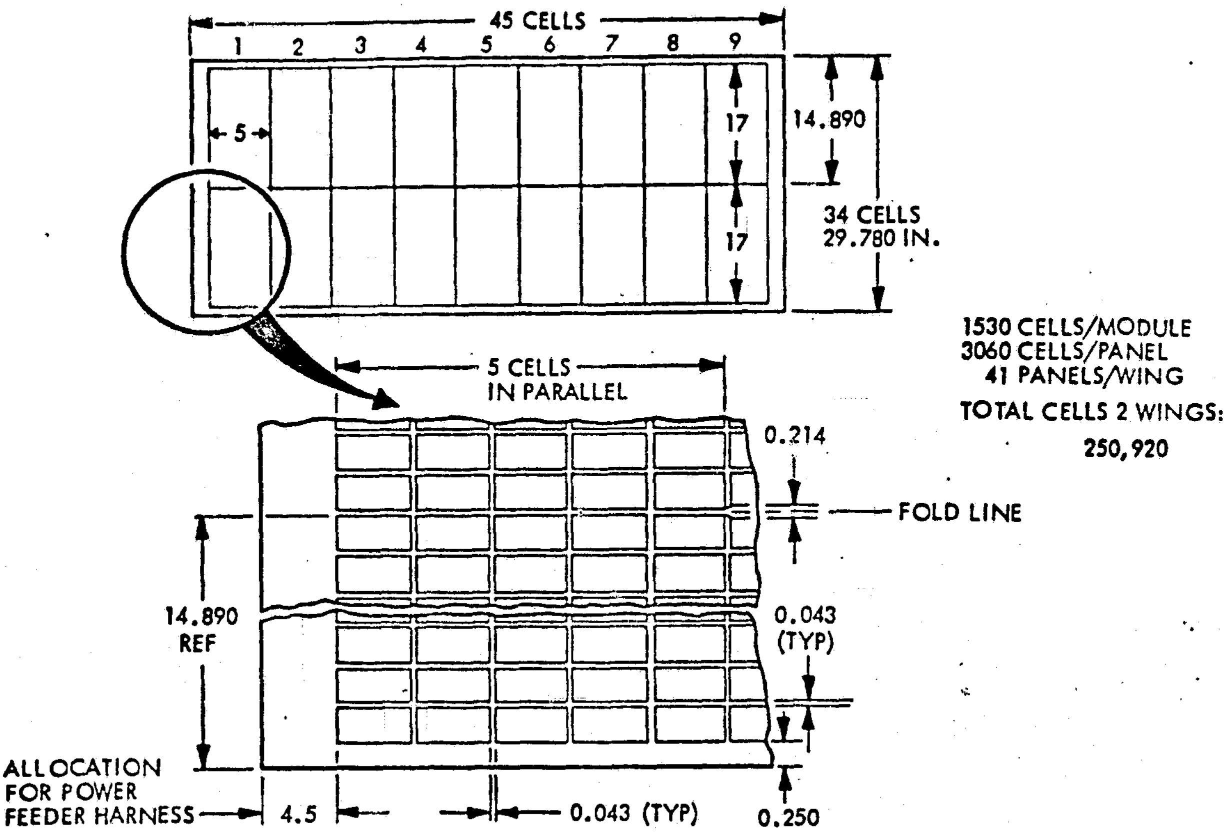


Figure 2-3 Array Panel Configuration

A summary of the weights of components of the SEP solar array wing is given in Table 2-2. As shown the total weight of the wing assembly is 176.9 Kg (390 lb.). The solar array blanket makes up 64% of this total.

2.2 Solar Cell Options

Two different solar cells were included in the study. The first is the present SEP array solar cell which is 2 cm x 4 cm and 200 μm thick. N-contacts are wrapped around the two short edges of the cell so all interconnect joints can be made from one side of the assembly. The efficiency of the cell is 11.4%, and its weight, taken from Reference 1, is 383 mg. The other cell is 2 cm x 2 cm by 50 μm thick and has conventional top-side N-contacts. The cell's specified efficiency is 11.0%, and its weight, based on data from Exhibit I of the contract document, is 78 mg.

Table 2-1

SEP SOLAR ARRAY WING DESIGN REQUIREMENTS

Parameter	Requirements
Electrical Power, BOL	25 KW, in free space at 1 AU
Point of Power Measurement	Input to power regulation, conditioning and control circuits
Operating Environment	Free space between 0.3 and 6 AU + MSFC defined geosynchronous mission
Operating Lifetime	Not less than 5 years
Electrical Power, EOL	21 KW, in free space at 1 AU
Power Degradation Limits	Degrade from BOL. 25 KW to 21 KW from all effects after 5 years at 1 AU, free space
Radiation Degradation Limits	Not more than 25% for a total equivalent 1 Mev electron fluence of 10^{15} electrons/square cm
Weight, including deployment mechanisms and all mounting bracketry	380 Kg
Stowage volume	0.456m (18 in.) x 0.456m (18 in.) x 3.56m (140 in.)
Deployment/Retraction	Full deployment, full retraction to and from intermediate positions of deployment, 50 cycles
No. of Intermediate Positions	One per mission, weights based on 30% deployed intermediate position
Range of Intermediate Positions	Design to allow range of 10% to 75% deployed intermediate positions
Deployed Array Dynamics Characteristics	Natural system vibration frequency greater than 0.04 Hz; in plane, normal to plane and torsional
Array Voltage	In range of 200 V_{mp} to 420 V_{oc} over particular SEP mission
Electrical and Dynamic Characteristics	Compatible with the SEP vehicle
Docking Loads	±0.5g with blanket retracted
Launch Environments	Defined in Section 6, MSFC Solar Array Technology Development Program Control Document, 1 Nov 1976
Reentry Loads	Defined in Section 6, MSFC Solar Array Technology Development Program Control Document, 1 Nov 1976

TABLE 2-2

SEP SOLAR ARRAY WEIGHT SUMMARY

	KG
MAST	32.04
GUIDE WIRE, INTERMEDIATE TENSION & FULL TENSION MECHANISMS	5.72
TENSION TRANSFER	0.018
MAST TIP FITTING	0.73
COVER ASSY	7.45
CONTAINER	10.10
SUPPORT STRUTS	1.21
SOLAR CELL BLANKET	113.18
ARRAY HARNESS	5.59
MISC NUTS & BOLTS	0.90
TOTAL	176.938
REQUIRED WEIGHT	190.00

SOLAR CELL BLANKET	113.18
LEADERS AND TENSION BARS	0.91
PANEL (41)	112.27
SUBSTRATE W/PADDING & STIFFENING	0.531
SOLAR CELLS (3060)	1.171
COVER ADHESIVE (3060)	0.130
COVER SLIDE (3060)	0.845
HINGE (2)	0.058
HINGE PIN (1)	0.003
TOTAL	2.738

2.3 Coverglass Options

Two coverglass options were included. Besides the SEP baseline cover which is 150 μm thick fused silica, a ceria-doped microsheet cover 75 μm thick is used for the higher power design which uses 2 x 4 cm cells and for all the 2 x 2 cm cell configurations.

2.4 Substrate Options

Three substrate designs were considered. The SEP baseline design substrate consists of printed-and-etched interconnect circuitry laminated between layers of Kapton. The circuit is made from 1 oz. (34 μm) copper. The substrate films consist of two 0.5 mil layers of Kapton, each coated with 0.5 mil polyester adhesive, heat-laminated together.

The second substrate option is the same as above except that it is designed for use with conventional solar cells. Therefore a different interconnect configuration is required, and a means of locating N-tabs onto the top side of the cells must be provided. This can be done by laminating the interconnects as before and then laser skiving small circular access areas around the tabs so they can be relocated onto the N-contacts.

2.5 Power Levels

Two power levels were studied: 12.5 kW and 17.5 kW. The lower value is the output of the present SEP solar array wing. For the higher output, designs were selected which minimize the changes to be made to the SEP baseline design. Thus, fabrication of flight hardware can be accomplished with a minimum of engineering development and qualification testing and with a high degree of confidence.

3.0 DESIGN MODIFICATIONS

Modifications to the SEP solar array baseline design were selected to incorporate 2 cm x 2 cm x 50 μm cells, the GE substrate design, and the higher 17.5 kW. Various possibilities for the size of the wing panels, the number of cells on each panel, and the series-parallel arrangements were considered. Since it is of interest to minimize the design changes required, it was determined that the best solution is to retain the same panel size for all cases and to use twice the number of cells when 2 x 2 cm cells are specified. As a result, the few other necessary design changes to the solar array wing assembly are made easily and with confidence in the modified wing's performance.

The following paragraphs describe in detail the design modifications made to the blanket, electrical harness, mast, and other parts of the assembly.

3.1 Solar Array Blanket

All the technologically significant design modifications are to the solar array blanket. These are covered in the following paragraphs.

3.1.1 New Interconnect Design for Conventional 2 cm by 2 cm Cell

A different interconnect design is required for Cases 2, 3, 5 and 6 which use the conventional 2 x 2 cm solar cell. After considering existing interconnect designs and the factors contributing to a good design, the configuration shown in Figure 3-1 was selected. Each interconnect part will be as long as required to connect the number of cells in parallel on an array electrical module. In our cases, this number is 10. Circuit redundancy is provided by having two contacts per cell per interconnect and by having multiple current paths between contacts on adjacent cells in both the series and parallel directions. In-plane stress relief loops between joints are incorporated approximately equally in both the series and parallel directions. Compared to using a serpentine trace for stress relief, the loop provides ample flexibility while having a much lower voltage drop due to circuit resistance between contacts in series.

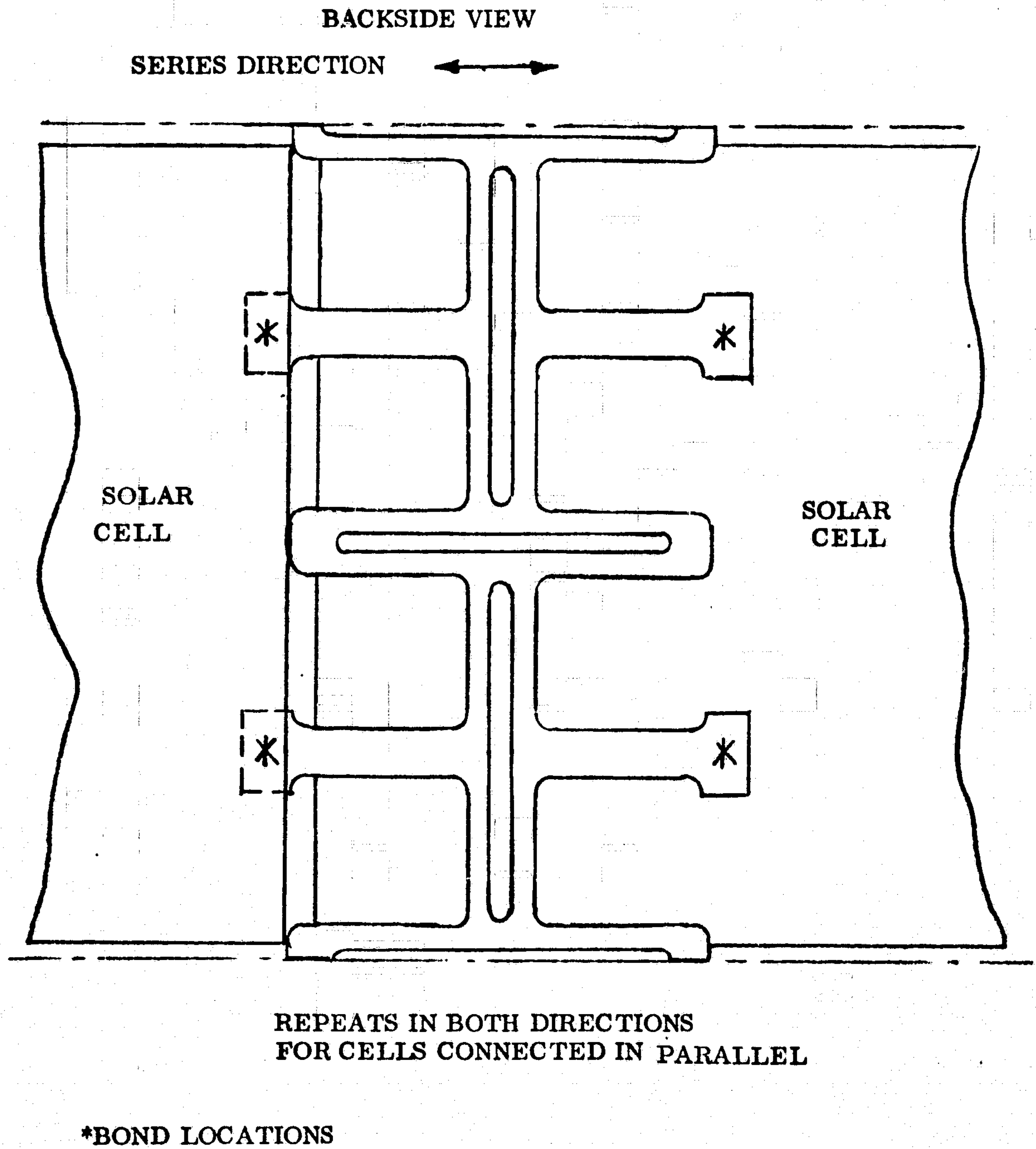


Figure 3-1 New Interconnect Configuration

One ounce (1.34 mil, or 34 μm) copper is the interconnect material selected because of its established capability and use on the SEP array design. However, other materials such as thinner copper, silver-plated molybdenum, or aluminum also could be used effectively with this interconnect configuration.

3.1.2 Cell Spacing

In the SEP baseline design (Case 1), the spacing between solar cells is 1.09 mm (.043 in.) the series and parallel directions, as shown in Figure 2-3. This is equivalent to a cell packing factor of 0.887. This spacing was selected also for the other configuration using 2 x 4 cm cells, Case 4. In the other four cases, the use of 2 x 2 cm cells results in twice the number of cell spaces. Since the same panel size and exactly twice the number of cells are to be used in these cases, the cell spacing must be reduced in the parallel direction. In the Extended Performance SEP Solar Array Study (Reference 2), a cell packing factor of 0.96 was established as being feasible for a 200 W/kg and a 240 W/kg array design using 75 μm and 50 μm conventional solar cells, respectively. Thus a 0.96 packing factor is selected in the cases, resulting in a slightly lower overall width for a submodule or higher assembly and more space for harness accommodation.

3.1.3 Harness

The SEP baseline (Case 1) harness design can be used also for Cases 2 and 3. For Cases 4, 5 and 6, the 57 panels producing 17.5 kW require a longer harness. The weight of this harness depends on the number of panels, the distance from the base of the array to each panel, and the criterion for allowable voltage drop. The voltage drop criterion used is the same as for the SEP design, viz., a power loss of 3.7 percent. Since the voltage drop (and power loss) is proportional to the harness length (ℓ) divided by its cross sectional area (A) and the weight (W) is proportional to ℓ times A, the harness weight required to keep the voltage drop constant is proportional to $(\ell/A) \cdot (\ell \times A) = \ell^2$. The total harness weight W for an assembly of panels is roughly proportional to the sum

$$W \propto (\ell^2 + (2\ell)^2 + (3\ell)^2 + \cdots + (n\ell)^2) = \ell^2 \sum_{K=1}^{n} K^2$$

where ℓ is the length of a panel (75.6 cm), and n is the total number of panels. The harness weight for 57 panels can be estimated by using the known weight of the SEP baseline design harness (5.59 kg) and scaling this value up from 41 to 57 panels as follows:

$$W(41) = \text{constant} \cdot \sum_{K=1}^{41} K^2 = \text{constant} \cdot 23{,}821 = 5.59 \text{ Kg}$$

$$W(57) = \text{constant} \cdot \sum_{K=1}^{57} K^2 = \text{constant} \cdot 63{,}365 = \frac{63{,}365}{23{,}821} (5.59) = 14.87 \text{ kg}$$

Thus the estimated harness weight for the 17.5 kW array designs (Cases 4, 5 and 6) is 14.87 kg.

3.1.4 Cell/Substrate Assembly

In the cases where 50 μm conventional solar cells are used, a problem arises due to the two N-contact pads. In covering the cell to provide radiation protection, either two small areas must be etched out of the square cover to give access for bonding the interconnect, or the cover must be put on after the interconnection is done. The latter technique was selected because it requires less costly covers, eliminates adhesive contamination in the interconnect bonding process, and probably will result in lower losses of cells and covers during assembly because (1) if a cell is damaged during welding, only a cell is lost instead of a cell/cover assembly, and (2) the job of cleaning the cover adhesive is easier. There will be sufficient room for the 34 μm thick N-tab since adhesive thickness is presently around 50 μm.

A typical array assembly procedure then might be as follows:

1. Etch interconnect circuit on substrate of 1/2 mil Kapton, 1/2 mil polyester. Laminate second Kapton/polyester layer.
2. Skive access holes in substrate.
3. Lay down array of cells upside down in registration tool.
4. Lay down substrate over cells and weld P-contacts.

5. Push N-tabs through between cells.

6. Flip assy. over and lay N-tabs down onto contact; weld N-contacts. Inspect (elec. output and visual).

7. Place cell covers in registration and hold-down tool, and apply adhesive.

8. Place covers onto interconnected cell assembly, apply necessary pressure to obtain thin, void-free adhesive layer, and cure adhesive.

3.1.5 Blanket Characteristics

Characteristics of the solar array blanket for the design selected in each of the 6 cases are tabulated in Tables 3-1 and 3-2.

In the SEP baseline design, there are 3060 2 x 4 cm solar cells on each of 41 panels. In Cases 2 and 3, using 2 x 2 cm cells, it was convenient to keep the same number and size of panels and simply double the number of cells, connecting 10 cells in parallel instead of 5. In Cases 4, 5 and 6, where a 17.5 kW wing is required, it was found that just increasing the number of panels to 57 provided the necessary power output.

Design calculations made and reference data used to obtain the values in Tables 3-1 and 3-2 are given in Appendix A.

The weights of the blanket components shown in Tables 3-1 and 3-2 were converted into weights per unit blanket area. The results are tabulated in Table 3-3. The total blanket weights per unit area for each design case were used as input data to the analysis of system natural frequency.

TABLE 3-1

BLANKET CHARACTERISTICS, 12.5 kW

ITEM	(1) SEP BASELINE	(2) SEP MOD. LMSC SUBSTRATE	(3) SEP MOD. GE SUBSTRATE
Solar Cell	2 x 4.044 cm, 200 μm 383 mg (48.051 kg/wing) 125,460 cells/wing	2 x 2 cm, 50 μm 78 mg (19.572 kg/wing) 250,920 cells/wing	2 x 2 cm, 50 μm 78 mg (19.572 kg/wing) 250,920 cells/wing
Coverglass	2 x 4.044 cm 276 mg (34.627 kg/wing) 150 μm (F.S.)	2 x 2 cm 78.6 mg (19.722 kg/wing) 75 μm (CMS)	2 x 2 cm 78.6 mg (19.722 kg/wing) 75 μm (CMS)
Coverglass Adhesive	50 μm thick 43.7 mg (5.483 kg/wing)	50 μm 21.6 mg (5.420 kg/wing)	50 μm 21.6 mg (5.420 kg/wing)
Printed Circuit Substrate	0.1358 kg/m^2 16.975 kg (wing)	0.1016 kg/m^2 12.694 kg (wing) Cu interconnect	0.1272 kg/m^2 15.781 kg (wing) Ag-Invar interconnect
Harness	Al; on outboard edges of blanket	Same as SEP baseline	Same as SEP baseline
Panel	4.00 x 0.756 m 306S x 5P cells/mod. 2 modules/panel	Same except 306S x 10P cells/mod. 2 modules/panel	Same
Wing	41 panels	41 panels	41 panels

TABLE 3-2

BLANKET CHARACTERISTICS, 17.5 kW

ITEM	(4) 2 x 4 CM CELLS SEP PC SUBSTRATE	(5) 2 x 2 CELLS SEP PC SUBSTRATE	(6) 2 x 2 CELLS GE SUBSTRATE/INTERCTS.
Solar Cell	2 x 4.044 cm, 200 μm 383 mg (66.803 kg/wing) 174,420 cells	2 x 2 cm, 50 μm 78 mg (27.210 kg/wing) 348,840 cells	2 x 2 cm, 50 μm 78 mg (27.210 kg/wing) 348,840 cells
Coverglass (CMS)	2 x 4.044 cm 75 μm thick 159 mg (27.733 kg/wing)	2 x 2 cm 75 μm 78.6 mg (27.419 kg/wing)	2 x 2 cm 75 μm 78.6 mg (27.419 kg/wing)
Coverglass Adhesive	50 μm 43.7 mg (7.622 kg/wing)	50 μm 21.6 mg (7.535 kg/wing)	50 μm 21.6 mg (7.535 kg/wing)
Printed Circuit Substrate	0.1358 kg/m^2 16.975 kg (wing)	0.1016 kg/m^2 12.694 kg (wing) Cu interconnect	0.1272 kg/m^2 15.781 kg (wing) Ag-Invar Interconnect
Harness	Al; on outboard edges of blanket	Same	Same
Panel	4.00 x 0.756 m 306S x 5P cells/mod. 2 modules/panel	Same except 306S x 10P cells	Same
Wing	57 Panels	57 Panels	57 Panels

TABLE 3-3

SOLAR ARRAY BLANKET AREA DENSITIES, KG/M^2

ITEM	1	2	3	4	5	6
1. CELLS	0.3873	0.1578	0.1578	0.3873	0.1578	0.1578
2. COVERGLASSES	0.2791	0.1590	0.1590	0.1608	0.1590	0.1590
3. ADHESIVE	0.0442	0.0437	0.0437	0.0442	0.0437	0.0437
TOTAL, ITEMS 1-3	0.7106	0.3605	0.3605	0.5923	0.3605	0.3605
4. PRINTED CIRCUIT SUBSTRATE	0.1320	0.1016	0.1280	0.1320	0.1016	0.1280
5. PADDING	0.0622	0.0382	0.0382	0.0622	0.0382	0.0382
6. STIFFENERS		0.0243	0.0243		0.0243	0.0243
TOTAL, ITEMS 1-6	0.9048	0.5246	0.5510	0.7865	0.5246	0.5510
7. HARNESS	0.0451	0.0451	0.0451	0.0862	0.0862	0.0862
TOTAL, ITEMS 1-7, BLANKET WT., KG/M^2 [LB/FT^2]	0.9499 [0.1946]	0.5697 [0.1167]	0.5961 [0.1221]	0.8727 [0.1787]	0.6108 [0.1251]	0.6372 [0.1305]

PANEL DIMENSIONS: .7564 M x 4.0005M = 3.026M^2 = 32.57 FT^2

3.2 Structures

In addition to the blanket and harness, the SEP solar array wing includes the following:

- Mast element and canister
- Mast tip fitting and array cover assembly
- Array container
- Support struts
- Tension mechanisms
- Guidewire mechanism

Of these items the mast and its canister are the heaviest and in the present SEP design account for 18 percent of the total weight of the wing assembly.

3.2.1 Mast Element and Canister

It was calculated what mast size and blanket tension would be required to meet the minimum natural frequency requirement of 0.04 Hz. Details of the analytical model assumed and the computer program written are included as Appendix B. In the SEP array, blanket tension is applied by three sets of wires. The first set pulls on a tension bar at the bottom of the array blanket. The second set extends the full length of the deployed array and functions as guidewires during retraction. These guidewires pass through holes at each hinge line on the array and have the general effect of adding tension to the blanket. The third set pulls on an intermediate tension bar and exists so that, as a second option, only an outboard portion of the array may be deployed.

The second and third sets need only minimum tension to function, and a value of 2 lbs. (0.9 kg) was selected primarily to overcome any friction in the mechanisms. The first set of wires, attached to the bottom of the array, then provide most of the total blanket tension. In the dynamic analysis the tension of this first set of wires is varied along with the mast radius to determine the minimum weight mast which will provide the specified stiffness.

The results of the analysis are presented in Table 3-4 and Figures 3-2 through 3-7. In Table 3-4, the array lowest natural frequency (first mode oscillation perpendicular to the plane of the blanket) is given for each case assuming the mast cross section

and blanket tension are kept the same as in the present SEP solar array design. These results could be considered if it were determined that a lower natural frequency than 0.04 Hz was acceptable.

TABLE 3-4

NATURAL FREQUENCY USING PRESENT SEP MAST RADIUS AND BLANKET TENSION

CASE NUMBER	1	2	3	4	5	6
NATURAL FREQUENCY, Hz	.043	.053	.052	.023	.027	.027

MAST RADIUS - 7.02 IN.
MAST STIFFNESS - 19.3 x 10^6 LB-IN
BLANKET TENSION - 21 LB (9.53 KG)
- BOTTOM TENSION - 17 LB
- INTERMEDIATE TENSION - 2 LB
- GUIDEWIRE TENSION - 2 LB

Figures 3-2 through 3-7 show the array lowest natural frequency as a function of total blanket tension for different mast radii. When the assumed mast size is too small for the minimum frequency requirement, the natural frequency of the system increases with blanket tension until the mast bows a certain amount and then it falls off as the tension increases and mast bows further. The procedure in the computer program was to start with a 5-inch radius mast and increase tension in 1 lb. increments. If the frequency does not reach 0.04 Hz and two successive calculations result in reduced frequencies, the process is terminated, the radius is increased by 0.5 inch, and the calculations repeated. Whenever 0.04 Hz is exceeded, the process is terminated, and the radius is increased another 0.5 inch and so on up to 10 inches. The minimum weight system is the one having the smallest mast radius which can provide the specified system natural frequency regardless of the blanket tension.

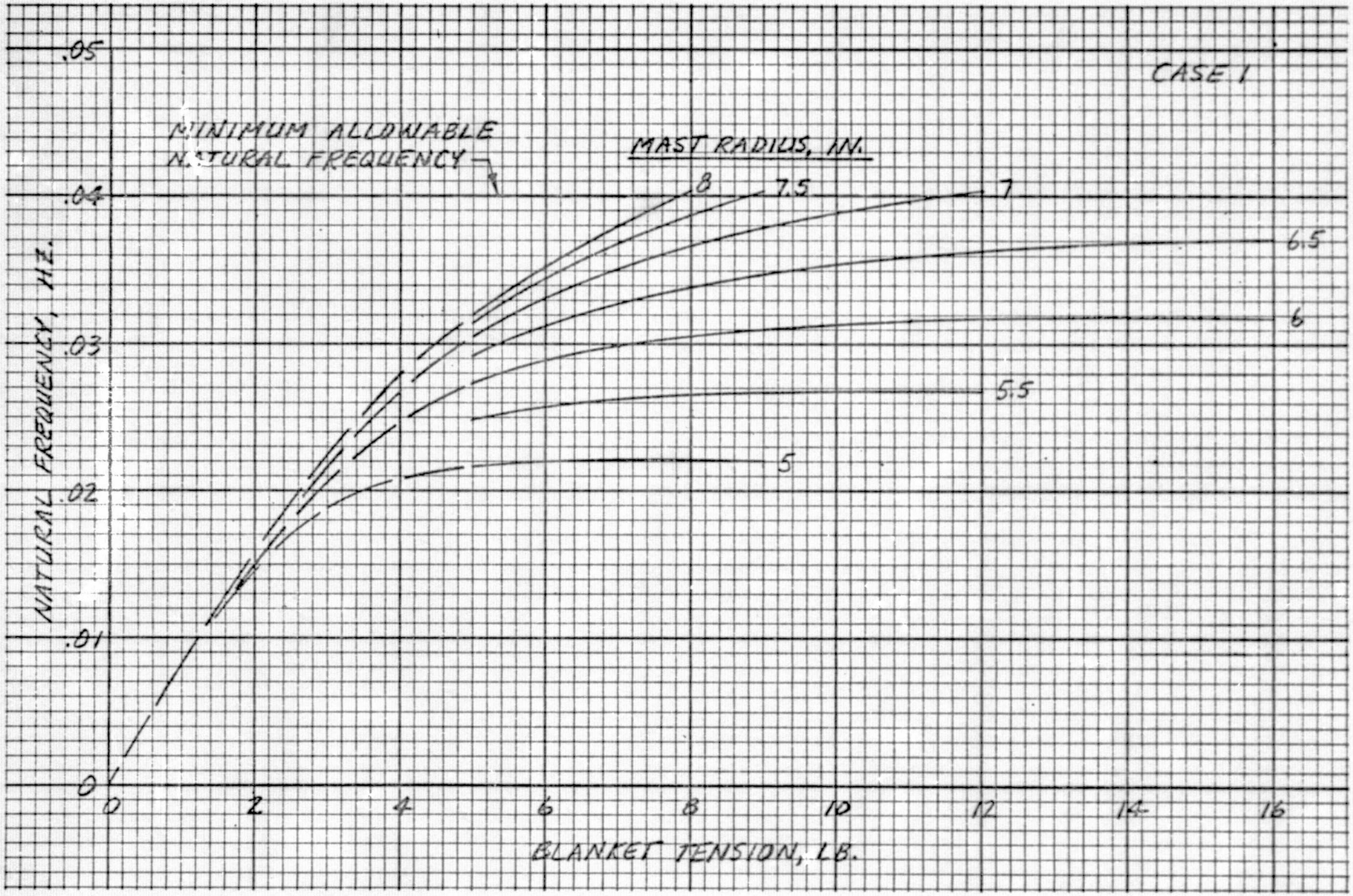


Figure 3-2 Natural Frequency vs Blanket Tension for Case 1

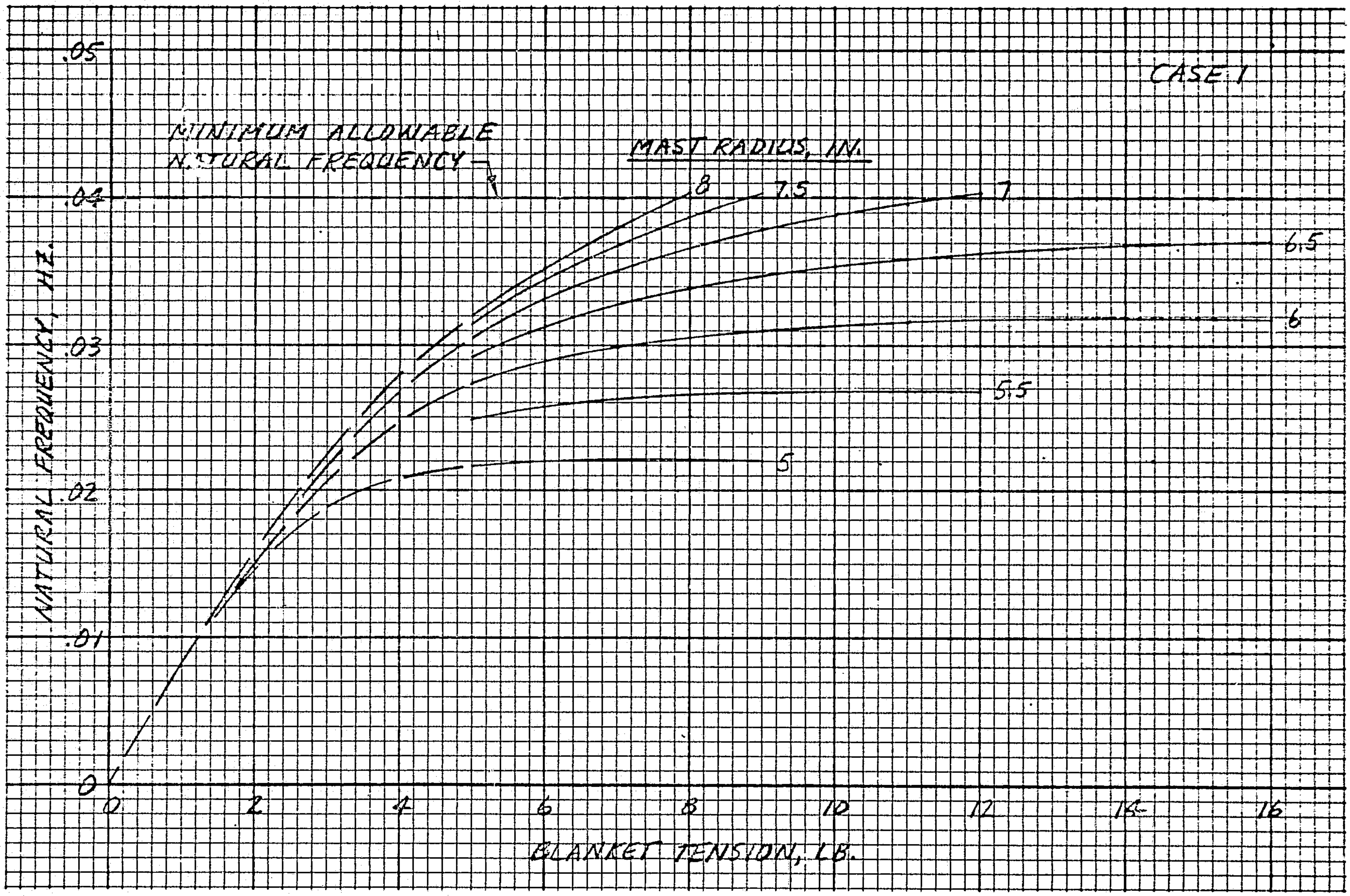


Figure 3-2 Natural Frequency vs Blanket Tension for Case 1

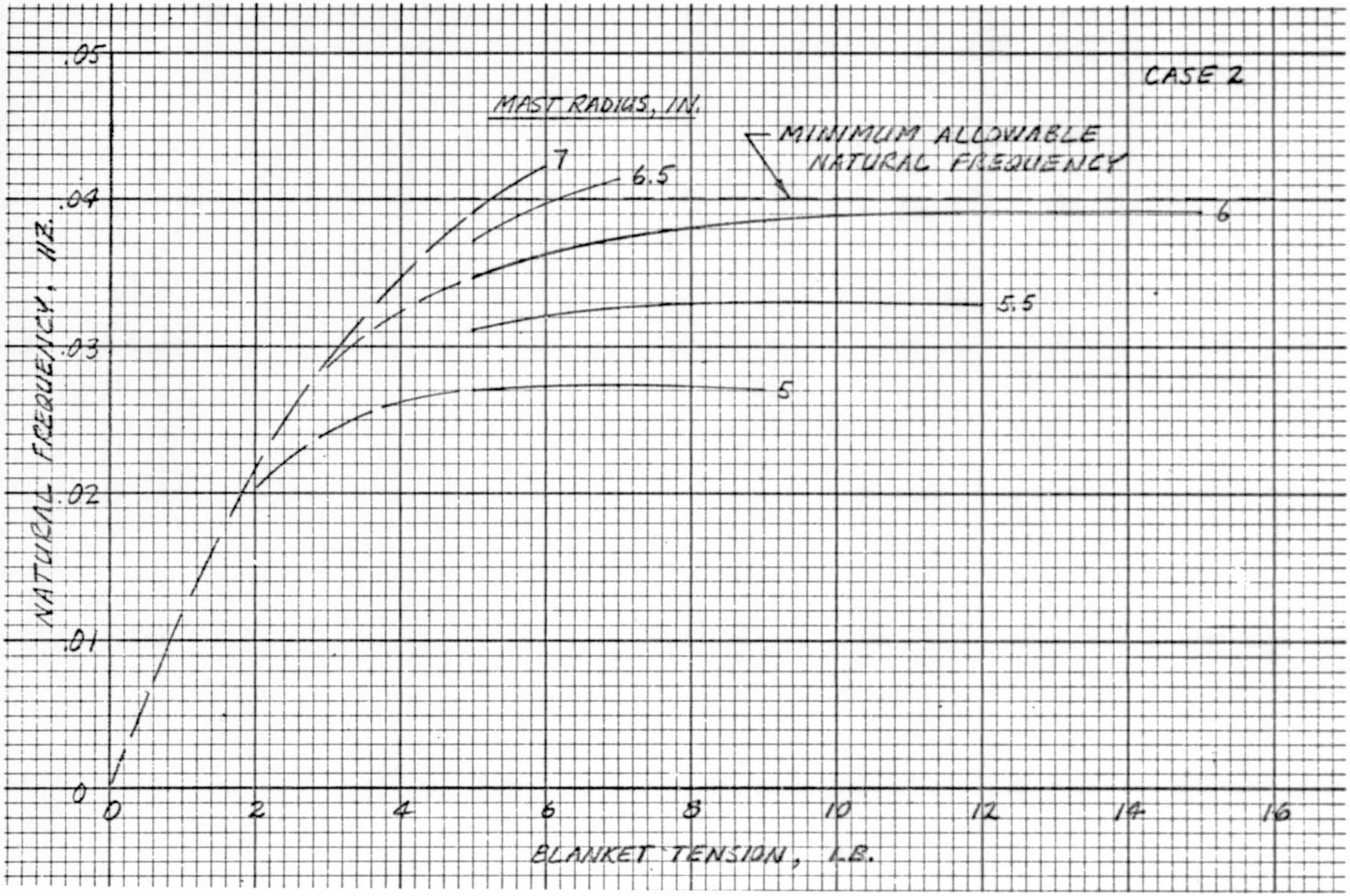


Figure 3-3 Natural Frequency vs Blanket Tension for Case 2

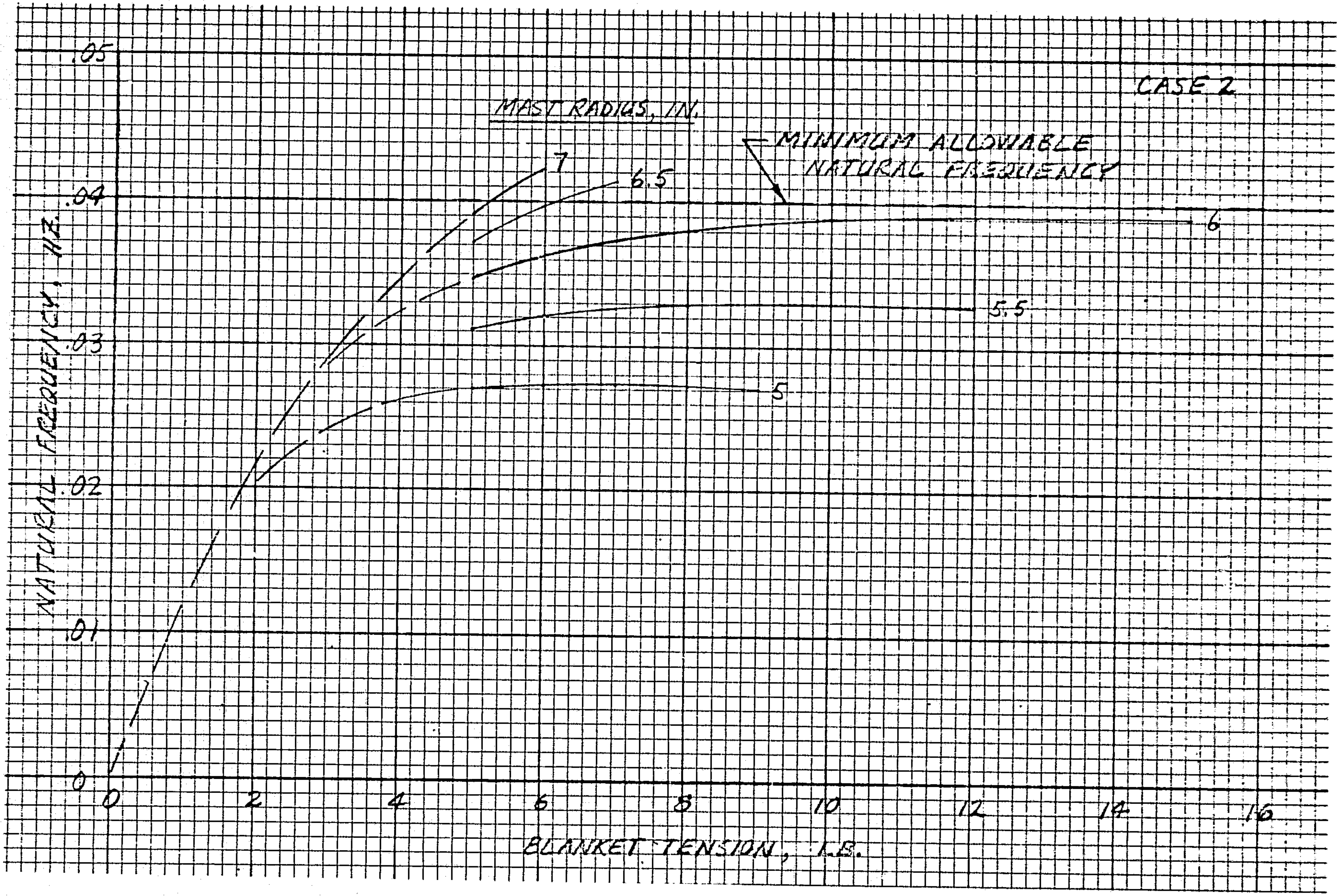


Figure 3-3 Natural Frequency vs Blanket Tension for Case 2

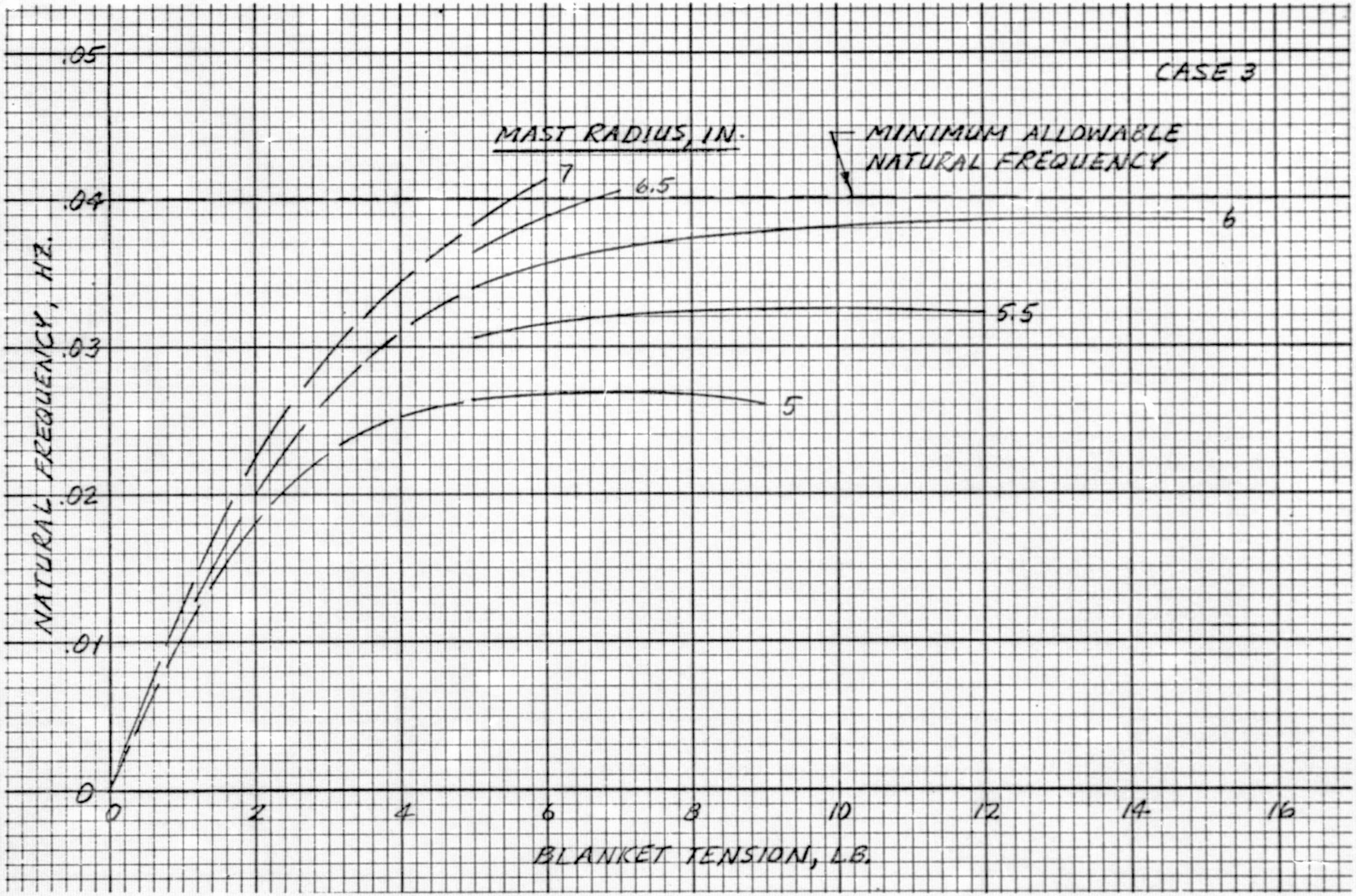


Figure 3-4 Natural Frequency vs Blanket Tension for Case 3

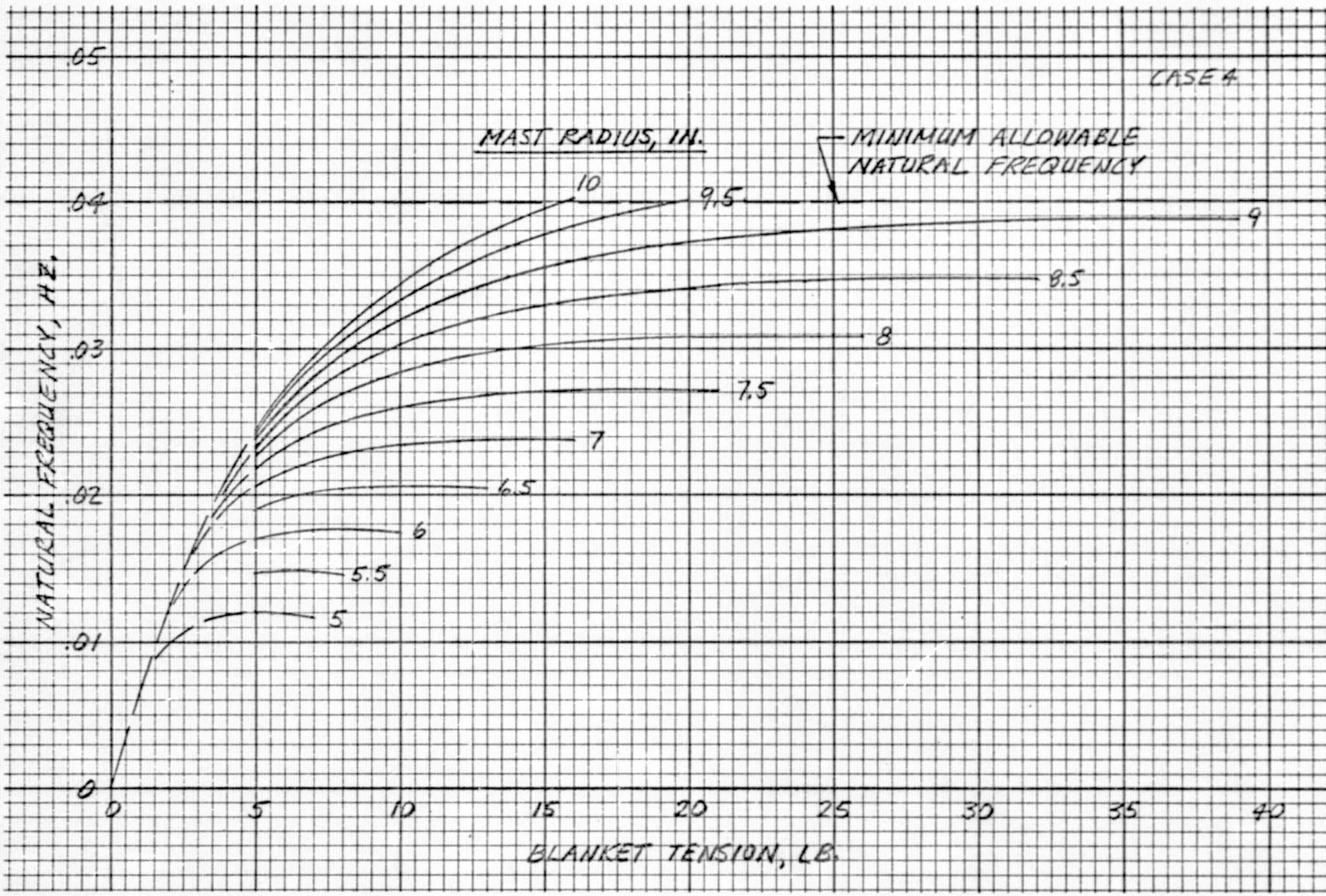


Figure 3-5 Natural Frequency vs Blanket Tension for Case 4

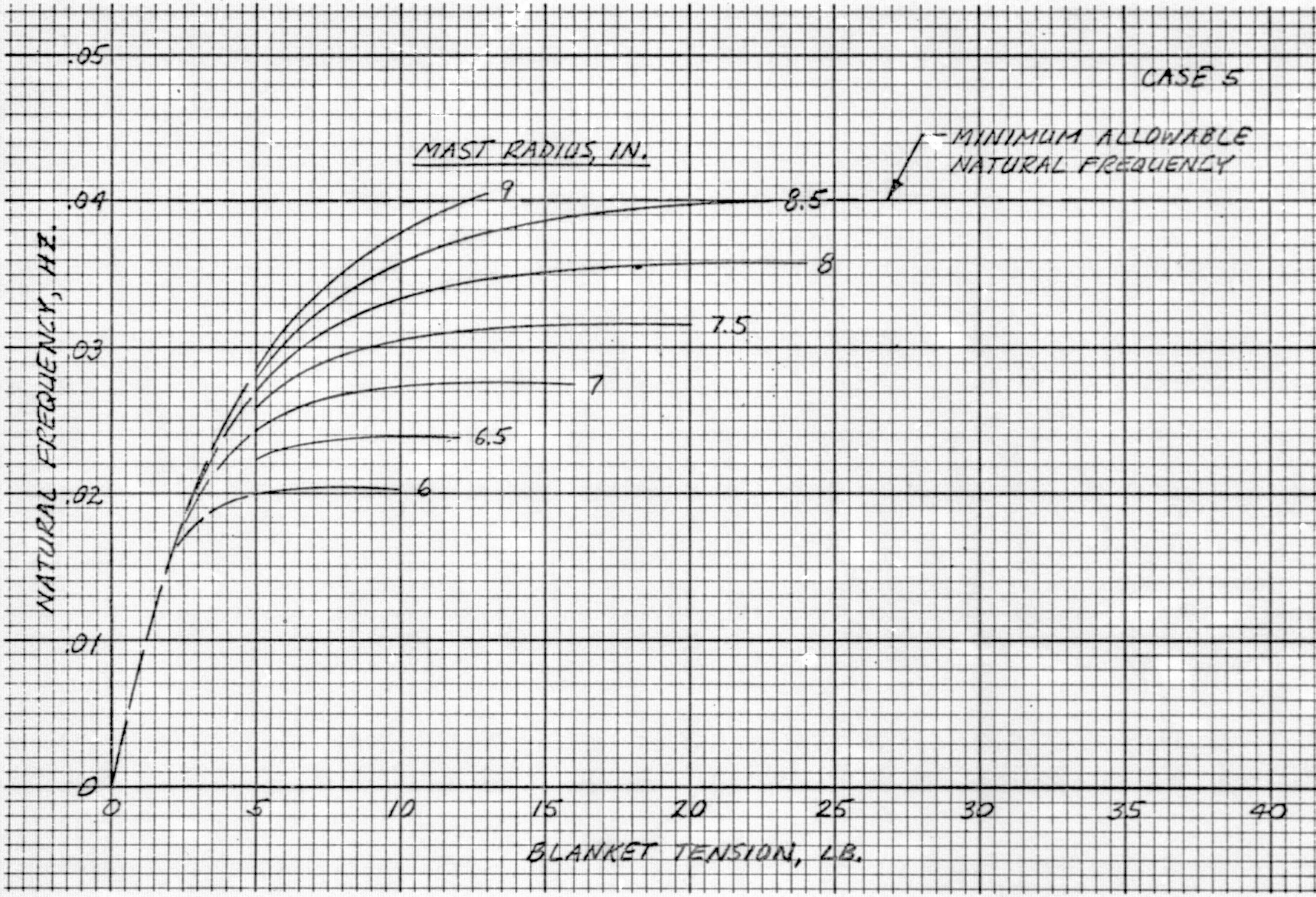


Figure 3-6 Natural Frequency vs Blanket Tension for Case 5

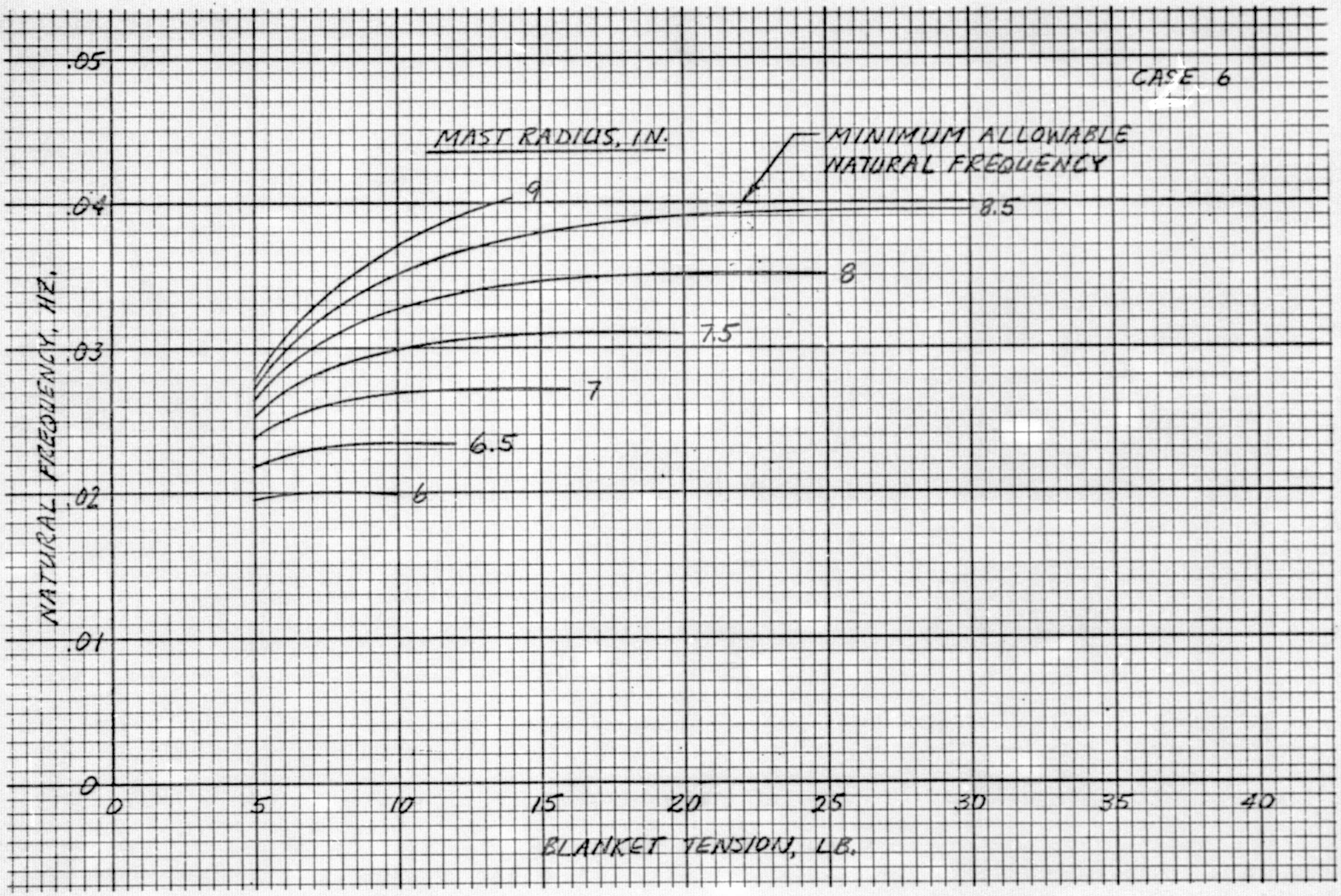


Figure 3-7 Natural Frequency vs Blanket Tension for Case 6

Table 3-5 gives for each case studied the minimum acceptable mast radius (within 0.5 inch), the mast element weight, the canister weight, and their combined weight. The formulas used to obtain weight as a function of mast radius and length were taken from Reference 3 and are based on measurements made on different-sized masts and canisters of the coilable, lattice type that have been built.

TABLE 3-5

MAST AND CANISTER WEIGHTS

WEIGHT FORMULAS FOR MAST ELEMENT AND CANISTER[1]

(a) $W_M = 3.26 \times 10^{-3} R^2 L$ (KG)

(b) $W_{CAN} = 2.36 \times 10^{-4} LR + 0.251R^2$ (KG)

WHERE
R IS IN INCHES AND
L IS IN FEET

	1	2	3	4	5	6
MIN. MAST RADIUS, IN.	--	6.5	6.5	9.5	8.5	9.0
MAST ELEMENT WT., KG	15.73[2]	14.30	14.30	42.22	33.80	37.89
CANISTER WT., KG	16.31[2]	10.76	10.76	22.97	18.42	20.64
TOTAL WT., MAST & CANISTER-KG	32.04	25.06	25.06	65.19	52.22	58.53

(1) FROM REFERENCE 3

(2) FROM REF. 1, PG. 3-31

3.2.2 Other Structures and Mechanisms

The remaining parts of the wing assembly, other than the blanket, harness, mast and canister, weigh less than 20 percent of the total. For these items, engineering estimates were made of their optimum weights in each of Cases 2 through 6. The estimates were based on the new blanket weights and a knowledge of the construction details of the SEP baseline parts and how they could be modified. The results are given in Section 3.4.

3.3 Array Power

Based on the SEP solar array design and the modifications made to it as described above, the array power was calculated for all 6 cases as follows:

I. 12.5 kW

A. CASE 1 - SEP BASELINE

CELL EFFICIENCY = 11.4% at 28°C
CELL AREA = 8.088 CM^2
TEMP. FACTOR TO 55°C = 0.865
= 1 - .5%/°C x (55-28), WHERE 0.5%/°C IS TEMP. COEFF.
SOLAR RADIATION INTENSITY AT 1 A.U. = 0.1353 W/CM^2
NO. OF CELLS = 41 x 3060 = 125,460
ARRAY OUTPUT LOSSES
SOLAR ARRAY ASSEMBLY - 3%
BUSSING (HARNESS) - 3.7%
BYPASS DIODES 0.5%

ARRAY WING POWER =

($0.1353\ W/CM^2$) x ($8.088\ CM^2$/CELL) x (125,460 CELLS) x (.114 EFF.)
x (0.865) x (1-.03) x (1-.037) x (1-.005) = 12,583 W

B. CASES 2 & 3 - 2 x 2 CM x 50 μM CELLS

DATA SAME EXCEPT:
CELL EFF. = 11.0% (SPECIFIED BY WORK STATEMENT)
CELL AREA = 4.00 CM^2
TEMP. FACTOR TO 55°C = 0.91 (BASED ON RECENT DATA FROM E. COSTOGUE, JPL)
= 1 - 0.33%/°C x (55-28) = 0.9109
NO. OF CELLS = 41 x 6120 = 250,920

ARRAY WING POWER =

0.1353 x 4.00 x 250,920 x .11 x .91 x .97 x .963 x .995 = 12,634 W

II 17.5 kW

C. CASE 4 - 2 x 4 CELLS WITH 150 μM COVERS

DATA SAME AS A EXCEPT:
NO. OF CELLS = 57 x 3060 = 174,420

ARRAY WING POWER =

0.1353 x 8.088 x 174,420 x .114 x 0.865 x .97 x .963 x .995 = 17,494 W

D. CASES 5 & 6 - 2 x 2 CM x 50 μM CELLS

DATA SAME AS B EXCEPT:
NO. OF CELLS = 57 x 6120 = 348,840

ARRAY WING POWER =

$$0.1353 \times 4.00 \times 348{,}840 \times .11 \times .91 \times .97 \times .963 \times .995 = \underline{17{,}565\ W}$$

3.4 Array Mass

A summary of weights of the solar array wing assembly is given in Table 3-6. Note that the blanket constitutes roughly 60 percent of the total weight in each case. Figure 3-8 is a bar chart presenting these weight distributions.

TABLE 3-6

WEIGHT SUMMARY, SOLAR ARRAY WING (KG)

ITEM	1	2	3	4	5	6
BLANKET	113.18	66.00	68.36	135.66	90.48	95.04
HARNESS	5.59	5.59	5.59	14.87	14.87	14.87
MAST & CANISTER	32.04	25.06	25.06	65.19	52.22	58.53
TIP FITTING & COVER ASSY.	8.18	6.76	6.85	9.67	7.76	7.95
CONTAINER	10.10	9.77	9.78	10.27	9.90	9.97
SUPPORT STRUTS	1.21	0.95	0.95	2.46	1.97	2.21
TENSION MECHANISMS	4.29	4.29	4.29	4.32	4.32	4.32
GUIDEWIRE MECHANISM	1.45	1.45	1.45	1.57	1.57	1.57
MISC. NUTS & BOLTS	0.90	0.90	0.90	0.90	0.90	0.90
TOTALS	176.94	120.77	123.23	244.10	183.99	195.36

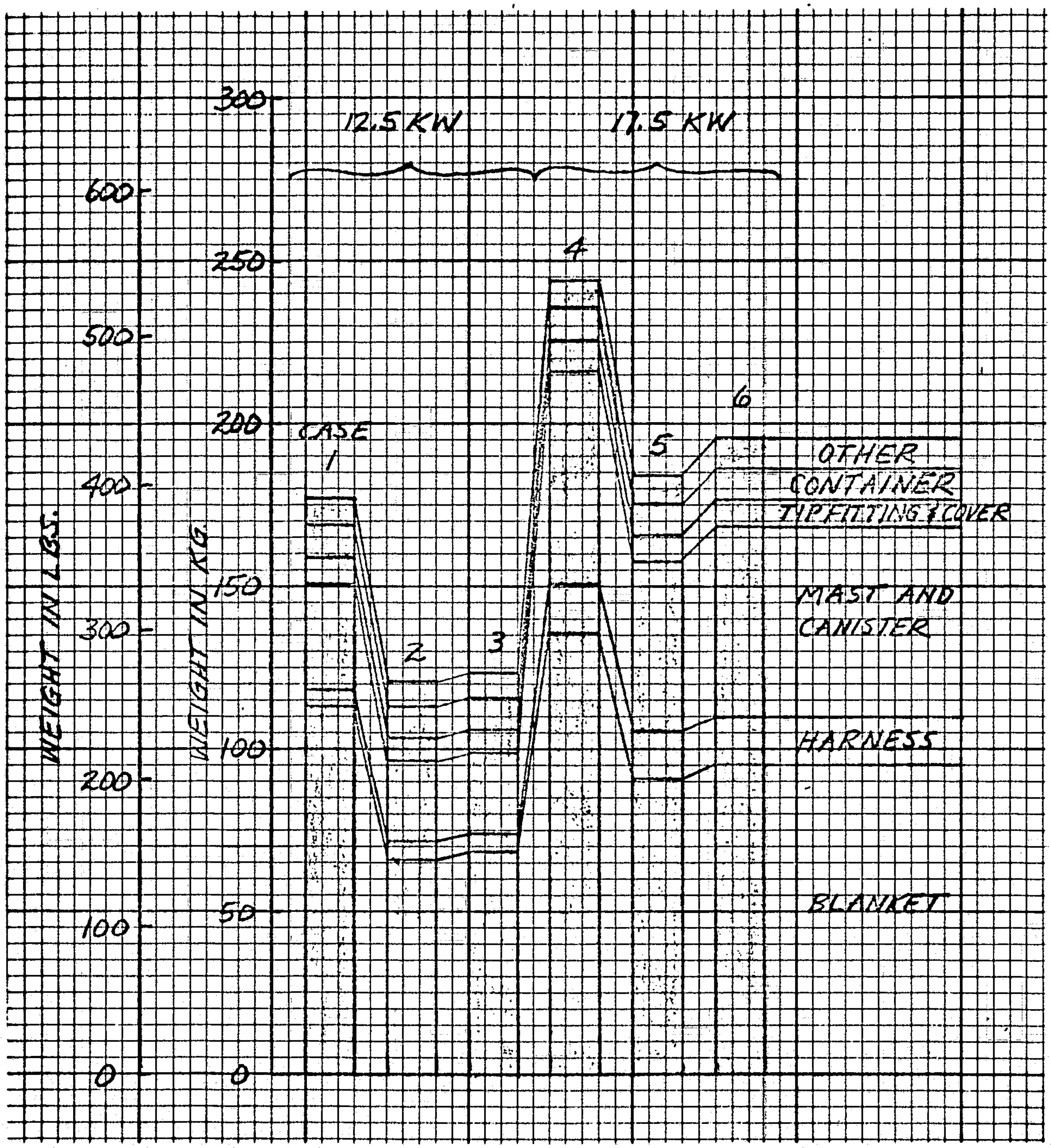


Figure 3-8 Breakdown of Solar Array Wing Weights

4.0 DESIGN LIMITATIONS AND TECHNOLOGY DEVELOPMENTS REQUIRED

4.1 Design Limitations

There are no known serious design limitations involved in the implementation of the design modifications. The most important potential limitations are with regard to the success of the new technology developments required. These developments are discussed in the following paragraph.

There are no difficulties anticipated in building the mast for any of the cases. Two manufacturers, Astro Research Corporation and AEC-Able Engineering Company, have built coilable, lattice booms of different sizes and Able Engineering has developed empirical design relationships (see Reference 3) applicable to the mast sizes required in this study.

The harness required for the 17.5 kW wing designs will be more than 2.5 times the weight and volume for the 12.5 kW cases to maintain the same percentage power loss. However, the stowed volume can be accommodated by reducing the thickness at the ends of the padding presently on the SEP array container and cover.

4.2 Technology Developments Required

Table 4-1 lists the technology developments necessary to be prepared for the fabrication of flight hardware and the design cases for which the development effort is required. A brief description of each item follows.

4.2.1 Solar Cell Coverglass Assembly

As discussed in Para. 3.1.4, a sequence and processes must be developed for bonding the N-tab and covering the cells when the conventional 2 cm by 2 cm cells are used. This work will involve assembly tooling design, development of handling techniques, and investigation of adhesive application methods and adhesive thickness required.

TABLE 4-1

TECHNOLOGY DEVELOPMENTS REQUIRED

ITEM NO.	DESCRIPTION	DEVELOPMENT TIME REQ'D	1	2	3	4	5	6
1	SOLAR CELL COVERGLASS ASSEMBLY	4 MO.		X	X		X	X
2	CELL/INTERCONNECT JOINING	6 MO.		X	X		X	X
3	PRINTED CIRCUIT SUBSTRATE FAB.	8 MO.		X	X		X	X
4	ELECTRICAL MODULE ASSEMBLY	4 MO.		X	X		X	X
5	SOLAR CELL REPLACEMENT	3 MO.		X	X		X	X
6	HANDLING OPERATIONS	3 MO.	X	X	X	X	X	X
7	BLANKET TEMP. CYCLING CAPABILITY	6 MO.		X	X		X	X
8	PARTICLE & UV RADIATION STABILITY	8 MO.		X	X	X	X	X
9	HARNESS ELEC/MECH PERFORMANCE	4 MO.				X	X	X

4.2.2 Cell/Interconnect Joining

Although LMSC has successfully welded interconnects to the front and back surfaces of 50 μm solar cells, it is important to develop processes for each new application in order to optimize the weld schedule and to develop tooling that will provide high production rates and yield percentage.

4.2.3 Printed Circuit Substrate Fabrication

More development is needed to improve the methods of printing, etching, laminating and skiving solar array substrates. Among the cases studied, this is especially true for the designs using conventional contact cells and a new interconnect configuration.

4.2.4 Electrical Module Assembly

This item is related to the first three but encompasses all the other assembly tools that will be needed to realize high production rates and negligible material in-process losses.

4.2.5 Solar Cell Replacement

When a solar cell in an assembly is defective, there must be a method for replacing that cell. In the SEP solar array development program, it has been successful to break the cell loose from the interconnect circuit, clean off the bond area of the interconnect, and weld in a new cell. In the case of the conventional 2 x 2 cm cell, new repair procedures need to be developed.

4.2.6 Handling Operations

In addition to assembly tools, handling tools and procedures must be developed for holding, moving and storing parts and subassemblies during fabrication and test.

4.2.7 Blanket Temperature Cycling Capability

Sample modules of each new design must be made and temperature-cycled to demonstrate their ability to withstand the temperature extremes and temperature cycling exposure. Design changes and repeated testing may be necessary to obtain satisfactory performance.

4.2.8 Particle and UV Radiation Stability

Samples of the specific materials to be used in the solar array and modules of the complete blanket assembly must be exposed to the required radiation levels to ensure acceptable performance. The samples should be temperature-cycled after exposure.

4.2.9 Harness Electrical/Mechanical Performance

The 17.5 kW solar array designs require a harness 2.5 times larger than the 12.5 kW designs. The present harness design needs to be reviewed and a prototype of the longer harness built to determine if it will fold neatly and without placing unacceptable stress on the blanket.

4.3 Hardware Testing

Several development, qualification and acceptance tests will be required. The major tests are identified in Table 4-2, along with the design cases where required. These tests are similar to those performed in the SEP Solar Array Technology Development Program. Descriptions of the SEP array tests can be found in Reference 1.

TABLE 4-2

HARDWARE TESTS

TEST	1	2	3	4	5	6
DEVELOPMENTAL HARDWARE TESTS						
• 12 OR 24-CELL MODULES FOR INTERC. DEVEL.	X	X	X	X	X	X
• 255 OR 510-CELL MODULES FOR TEMP. CYCLING	X	X	X	X	X	X
• MAST SECTION FUNCTIONAL		X	X	X	X	X
• ARRAY WING ROOT SECTION – VIBRATION		X	X	X	X	X
• ROOT SECTION – ZERO-G DEPLOY/RETRACT		X	X	X	X	X
FLIGHT HARDWARE TESTS						
• PANEL ELECTRICAL OUTPUT	X	X	X	X	X	X
• MAST EXTENSION/RETRACTION	X	X	X	X	X	X
• MAST STIFFNESS	X	X	X	X	X	X
• WING ASSY EXTENSION/RETRACTION	X	X	X	X	X	X

5.0 COST ESTIMATES FOR IMPLEMENTATION

Tables 5-1 and 5-2 present preliminary cost estimates for the design, technology development, qualification and fabrication of one and two wings, respectively, in each of the 6 cases. These estimates are based on a number of previous rough estimates that have been prepared for SEP-type solar arrays and a review of the cost of similar technology developments made at LMSC in both Contract and Independent Development work.

Table 5-3 identifies tasks under each of the cost elements in Tables 5-1 and 5-2 and indicates in which cases a task is not necessary, i.e., where tasks have already been accomplished in the SEP Solar Array development program.

TABLE 5-1

COST ESTIMATE, ONE SOLAR ARRAY WING - M$

COST ELEMENT	1	2	3	4	5	6
DESIGN & DEVELOPMENT	0.1	0.5	0.6	2.0	2.4	2.5
PRODUCTION PROCESS DEVELOPMENT	0.5	1.0	1.2	0.5	1.0	1.2
TOOLING & SPECIAL TEST EQUIPMENT	0.5	0.8	0.9	0.5	0.8	0.9
QUALIFICATION TESTING	0.5	1.0	1.0	0.8	1.3	1.3
WING FABRICATION	5.4	6.5	6.5	7.6	9.1	9.1
OTHER	0.2	0.3	0.3	0.4	0.5	0.5
TOTAL PROGRAM	7.2	10.1	10.5	11.8	15.1	15.5

TABLE 5-2

COST ESTIMATE, TWO SOLAR ARRAY WINGS - M$

	1	2	3	4	5	6
DESIGN & DEVELOPMENT	0.1	0.5	0.6	2.0	2.4	2.5
PRODUCTION PROCESS DEVELOPMENT	0.5	1.0	1.2	0.5	1.0	1.2
TOOLING & SPECIAL TEST EQUIPMENT	0.6	0.9	1.0	0.6	0.9	1.0
QUALIFICATION TESTING	0.6	1.2	1.2	1.0	1.5	1.5
WING FABRICATION	10.8	13.0	13.0	15.2	18.2	18.2
OTHER	0.3	0.4	0.4	0.5	0.6	0.6
TOTAL PROGRAM	12.9	17.0	17.4	19.8	24.6	25.0

TABLE 5-3

COST BREAKDOWN, 1 WING - K$

ITEM NO.	DESCRIPTION	1	2	3	4	5	6
1.0	DESIGN & DEVELOPMENT	100	500	600	2000	2400	2500
1.1	INTERCONNECT	NA[1]			NA		
1.2	CELL COVER ASSY	NA					
1.3	SUBSTRATE	NA			NA		
1.4	HARNESS	NA	NA	NA			
1.5	MAST	NA					
1.6	OTHER STRUCTURE, MECHANISMS	NA					
1.7	SYSTEM & SUBSYSTEM TESTING	NA					
1.8	Q.A. RELATED TO DEV.	NA					
2.0	PRODUCTION PROCESS DEVELOPMENT	500	1000	1200	500	1000	1200
2.1	CELL COVERGLASS ASSEMBLY	NA					
2.2	CELL/INTERCONNECT JOINING						
2.3	PRINTED CIRCUIT SUBSTRATE FAB.						
2.4	ELECTRICAL MODULE ASSEMBLY						
2.5	GRAPHITE COMPOSITE STRUCTURES						
2.6	HANDLING OPERATIONS						
3.0	TOOLING & SPECIAL TEST EQUIPMENT	500	800	900	500	800	900
3.1	CELL REGISTRATION	NA			NA		
3.2	INTERCONNECT ETCHING PATTERN	NA			NA		
3.3	INTERC. N-TAB FORMING	NA			NA		
3.4	LASER SKIVING MASK	NA			NA		
3.5	ELECTRICAL MODULE ASSY/HANDLING						
3.6	TEST EQMT-ELECTRICAL OUTPUT	NA	NA	NA	NA	NA	NA
3.7	TEST EQMT-ARRAY DEPLOYMENT	NA	NA	NA			

[1] NOT APPLICABLE

TABLE 5-3 (cont.)

COST BREAKDOWN, 1 WING - K$

ITEM NO.	DESCRIPTION	1	2	3	4	5	6
4.0	QUALIFICATION TESTING[2]	500	1000	1000	800	1300	1300
4.1	TEMP. CYCLE OF ELECTR. MODULE						
4.2	BOOM STIFFNESS						
4.3	ARRAY DEPLOYMENT/RETRACTION						
4.4	ZERO-G TESTING OF ARRAY						
4.5	QA RELATED TO QUAL. TESTING						
5.0	WING FABRICATION[3]	5400	6500	6500	7600	9100	9100
5.1	SOLAR CELL PROCUREMENT						
5.2	COVERGLASS PROCUREMENT						
5.3	SUBSTRATE						
5.4	MODULE ASSY.						
5.5	EXTENSION MAST & CANISTER						
5.6	OTHER STRUCTURES/MECHANISMS						
5.7	MFG. & ACCEPTANCE TESTING						
5.8	QA RELATED TO WING FAB.						
6.0	OTHER	200	300	300	400	500	500
6.1	PROGRAM MGT. & REPORTING						
6.2	SUBCONTRACT MGT. (MAST)						
6.3	GROUND SUPPORT EQUIPMENT						
6.4	CUSTOMER SUPPORT						

[2] INCLUDING TEST PLANS & PROCEDURES

[3] INCLUDING MATERIAL COST

6.0 CONCLUSIONS

The work done in this study has resulted in several conclusions related to the feasibility of building a flight solar array based on ultralow-mass technology at the 12.5 kW and 17.5 kW per wing power levels. These are noted below.

1. The structural modifications needed to the existing SEP solar array design to incorporate the specified ultralow-mass blanket technology are minor in their nature and can be implemented routinely.

2. All of the significant risk factors are in the ultralow-mass blanket technology rather than in their incorporation on a SEP-type array.

3. Only minor modifications to structures other than the mast and canister are indicated, and these are due mainly to opportunities to reduce structure weight because of the lower blanket mass.

4. The mast and its canister can be built in any of the calculated minimum-weight system sizes, based on the present SEP coilable lattice mast and the extensive fabrication experience of two manufacturers.

5. The best choice of panel size appears to be the present SEP panel size for all 6 study cases, with the number of 2 x 2 cm solar cells exactly double that of the SEP baseline design which has 3,060 2 x 4 cm cells, and an increase from 41 to 57 panels to generate 17.5 kW.

6. The minimum natural frequency requirement can be met in all cases by a minimum-weight system in which mast radius varies between 6.5 in. and 9.5 in. and maximum tension on the blanket varies between 6.2 lb. and 23.0 lb.

7. The amount of qualification testing of flight hardware can be scaled down due to the status of the SEP solar array development program. The reduction in testing will depend on the power level selected.

8. Several technologies involved in the implementation of ultralow-mass blanket designs and large area fabrication processes require further development and demonstration. These technologies include welding of 50 μm cells, interconnect and substrate fabrication processes, and coverglass assembly methods.

7.0 NEW TECHNOLOGY

No reportable items of new technology have been identified.

REFERENCES

1. "Solar Array Technology Development for SEP (Solar Electric Propulsion) Mid-term Report," NAS8-31352, LMSC-D492693, 18 January 1977.

2. "Extended Performance SEP Solar Array Study," LMSC-D573740, Solar Array Technology Development for SEP Program, NAS8-31352, 29 July 1977.

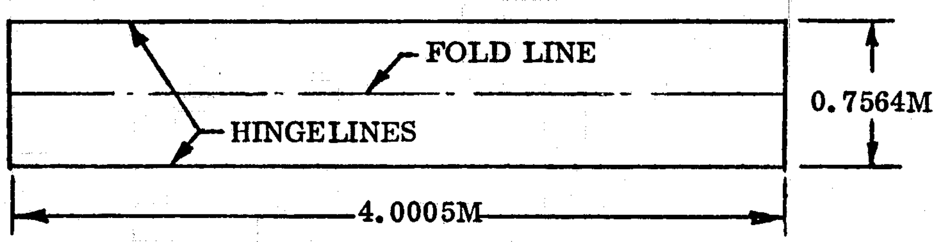
3. "Parametric Data for Coilable Lattice Booms for Deploying and Supporting Solar Cell Arrays from Spacecraft," by R. F. Crawford, AEC-Able Engineering Company, Inc., AECR7821/115, May 12, 1978.

4. "Solar Cell Array Design Handbook. Volume 2," JPL SP 43-38, Vol II, October 1976.

APPENDIX A
DESIGN CALCULATIONS

A. <u>PANEL SIZE:</u>

FROM MID-TERM RPT. P. 3-6.



AREA = 0.7564 x 4.0005 = 3.0259782 M^2 USE <u>3.026 M^2</u>

$$\frac{3.026}{(.3048)^2} = 32.57159\ FT^2 \qquad \text{USE } 32.57\ FT^2$$

B. <u>NO. OF PANELS ON WING:</u>

FOR 12.5 KW <u>41 PANELS</u>

FOR 17.5 KW <u>57 PANELS</u>

C. <u>SOLAR CELL DIMENSIONS AND NO. PER PANEL</u>

FOR CASES 1 & 4: 2 CM x 4.044 CM x 200 μM, <u>3060</u> CELLS/PANEL

FOR CASES 2, 3, 5 & 6: 2 CM x 2 CM x 50 μM, <u>6120 CELLS/P</u>

D. <u>SOLAR CELL WEIGHTS:</u>

2 x 4 CM: FROM MIDTERM RPT: $\frac{1.171\ KG \times 10^6}{3060}$ = 382.680 MG

USE <u>383 MG</u>

2 x 2 CM: FROM EXHIBIT I: <u>78 MG</u>

E. <u>COVERGLASS DIMENSIONS AND WEIGHT:</u>

CASE 1: 2 CM x 4.044 CM x 150 μM

FROM MID-TERM RPT, P. 3-34: $\frac{0.845 \times 10^6}{3060}$ = 276.144 MG

USE <u>276 MG</u>

CASES 2, 3, 5, 6: 2 CM x 2 CM x 75 μM

FROM SOLAR CELL ARRAY HANDBOOK, VOL. 2, P. 7.3-3:

DENSITY OF CERIA-DOPED MICROSHEET = 2.62 G/CM^3

$$\text{WT.} = 2\text{ CM} \times 2\text{ CM} \times 75\,\mu\text{M} \times 2.62\,\frac{\text{G}}{\text{CM}^3} \times 10^3 = \underline{78.6\text{ MG}}$$

CASE 4: 2 CM x 4.044 CM x 75μM

$$\text{WT} = 2 \times 4.044 \times .0075\text{ CM} \times 2.62\text{ G/CM}^3 = 0.158929\text{ G}$$

USE <u>159 MG</u>

F. <u>COVERGLASS ADHESIVE WEIGHT:</u>

DENSITY = 1.08 G/CM^3 (FROM SOLAR CELL ARRAY HNDBK., VOL. 2, P 7.3-4)

THICKNESS = 50 μM

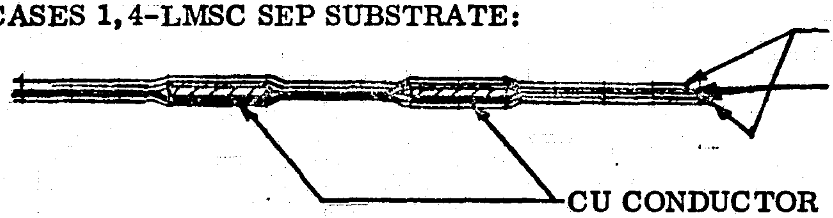
CASES 1 & 4: WT. = 2x4.044 x .0050 CM x 1.08 G/CM^3 = 0.043675G

USE <u>0.0437 G</u>

CASES 2, 3, 5 & 6: WT. = 2 x 2 x .005 CM x 1.08 G/CM^3 = <u>0.0216</u> G

G. <u>PRINTED CIRCUIT SUBSTRATE:</u>

CASES 1, 4-LMSC SEP SUBSTRATE:



AREA DENSITY:

SUBSTRATE:

$$2 \times .0005'' \times 2.54\,(\underset{\text{Kapton}}{1.42\text{ G/CM}^3} + \underset{\text{Polyester}}{1.38\text{ G/CM}^3}) \times 10 = 0.07112\text{ KG/M}^2$$

FROM MID-TERM REPORT, P. 3-38: INTERCONNECT CIRCUIT COVERS 20% OF SUBSTRATE AREA

$$\text{INTERC. THICKNESS} = \frac{1\text{ OZ/FT}^2\,(28.349\text{ G/OZ})}{8.94\text{ G/CM}^3\,(30.48)^2\,\frac{\text{CM}^2}{\text{FT}^2}} = 3.41327 \times 10^{-3}\text{ CM}$$

$$= 1.3438\text{ MILS}$$

<u>USE 1.34 MILS</u>

INTERC. AREA DENSITY:

$$8.94\ G/CM^3\ (.00134 \times 2.54\ CM) \times 20\% \times 10 = 0.06086\ KG/M^2$$

TOTAL: $0.07112 + 0.06086 = 0.13198\ KG/M^2$

USE $\underline{0.1320\ KG/M^2}$

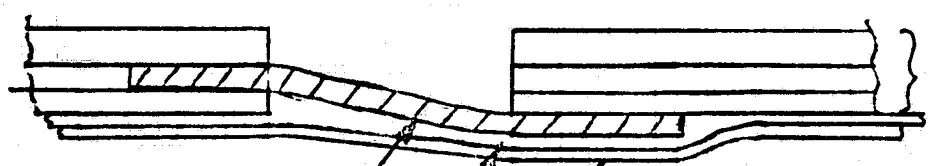
CASES 2, 5 - LMSC SUBSTRATE FOR 2 x 2 CONV. CELL

SAME AS ABOVE EXCEPT NEW INTERCONNECT CONFIGURATION WITH 10% AREA COVERAGE

$$WT/AREA = 0.07112 + 0.06086\ \frac{10\%}{20\%} = 0.10155\ KG/M^2$$

USE $\underline{0.1016\ KG/M^2}$

CASES 3, 6 - GE SUBSTRATE



RTV-655 DENSITY = $1.07\ G/CM^3$ (FROM GE PRODUCT DATA BULLETIN DAB764/DN173)

KAPTON-H DENSITY = $1.42\ G/CM^3$ (FROM SOLAR CELL ARRAY HNDBK VOL. 2, P. 7.3-3)

INTERCON. WT. PER CELL = 32 MG (FROM EXHIBIT I, P. 5)

$$AREA\ DENSITY = .001 \times 2.54\ CM\ (1.07 + 1.42\ G/CM^3) \times 10\ \frac{KG\text{-}CM^2}{G \cdot M^2}$$

$$+\ 32\ \frac{MG}{CELL} \cdot \frac{6120\ CELLS/PANEL}{3.026\ M^2/PANEL} \cdot 10^{-6}\ \frac{KG}{MG}$$

$$= 0.063246 + 0.0647191 = 0.127965\ \frac{KG}{M^2}$$

USE $\underline{0.128\ KG/M^2}$

ENGINEERING MEMORANDUM

TITLE: SEP SOLAR ARRAY, MODIFICATIONS FOR JPL	EM NO. SP/826 REF: 62-62
PREPARED BY: A. S. Benson CHECKED BY:	DATE: 6-30-78 APPROVAL:

PURPOSE

At the request of G. J. Antonides, 0/62-25, a parametric variation study of the SEP baseline solar array, and five structural variations, has been conducted to minimize boom weight with the constraint of a lower bound to the fundamental out-of-plane cantilever normal mode frequency. The two significant parameters to be varied are boom radius and preload.

In a conversation with T. W. Havas, Jr., 0/62-62, the conclusion was that this study could not be conducted within the time limit using the finite element model approach used by the existing computer program SOLAR*DYN.

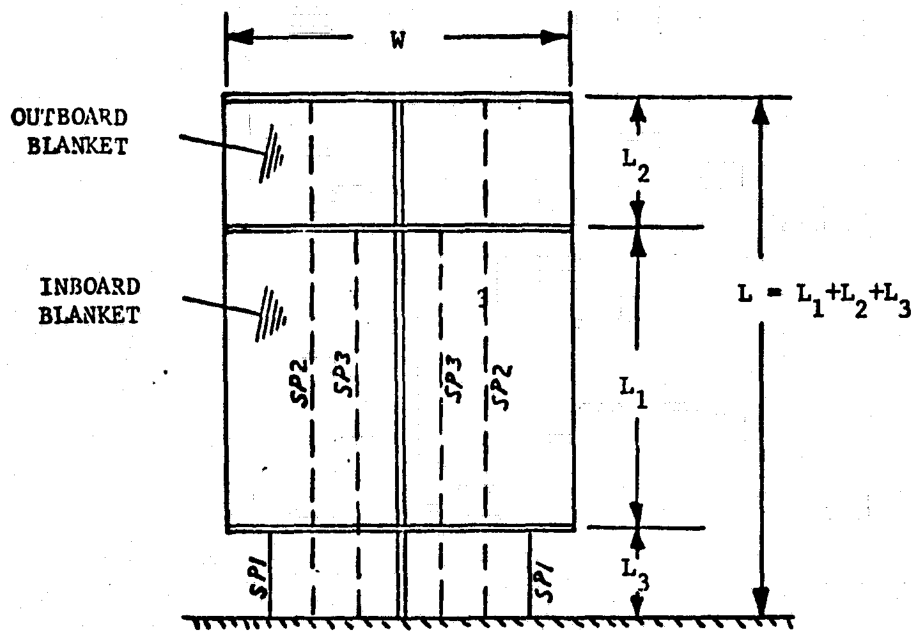
In a further conversation with D. E. Lindberg, 0/62-25, and G. J. Antonides, 0/62-25, the writer suggested, as an alternative, that an existing closed-form solution could be readily modified to obtain the requested information within the prescribed time limit. The fact was pointed out that the closed-form solution had not yet been generalized to include coupled bending and torsion motion, but that the model only handled out-of-plane bending and further that no loading eccentricity at the tip of the boom would be included. The consensus was that the eccentricity of 6.5 inches compared to a length of 1200. inches would be of secondary importance and further that previous studies had indicated that torsion need not be included in the optimization of the weight with respect to the fundamental frequency.

The weight optimization was to be conducted, varying boom radius (in 0.5 inch increments) and varying preload (in 1.0 pound increments). The requirement was that the fundamental frequency should not be less than 0.04 Hz.

The solar array model is shown in the following sketch.

FORM LMSC 2700

Prepared by A. S. Benson	Date 6-30-73	LOCKHEED MISSILES & SPACE COMPANY. INC.	Page 2 Temp. Perm.
Checked by:	Date	Title SEP SOLAR ARRAY, MODIFICATIONS FOR JPL	Model
Approved by:	Date		Report No. SP/826



CANTILEVER SUPPORT

The model consists of a central boom, of length L, of uniform mass and stiffness, an inboard and outboard blanket (each of uniform density per unit area), and three rigid cross members. The upper cross member attaches the outboard blanket to the tip of the boom. The other two cross members are attached to the blankets -- but not to the boom. In addition to these members, three sets of springs or tension wires are introduced. The two springs, SP1, serve to attach the lower blanket to the base. The value of SP1 (the lower spring tension) is varied in this study. A set of imbedded wires, SP2, with a pretension of 2 pounds extend the full length of the array. A third set, SP2, (with a pretension of 2 pounds) connects the intermediate cross member to the base.

The central boom is assumed to behave as a beam column and that each blanket region is under uniform tension and deflects into a singly-curved surface in normal mode oscillation. With these problem constraints, a closed form solution (developed by A. S. Benson) is employed; equilibrium and boundary conditions are satisfied for the principal mass elements. The 2 lower cross members were judged to be of negligible weight as were the three sets of wires/springs.

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Prepared by A. S. Benson	Date 6-30-78	LOCKHEED MISSILES & SPACE COMPANY, INC.	Page 3
Checked by:	Date	Title SEP SOLAR ARRAY, MODIFICATIONS FOR JPL	Model
Approved by:	Date		Report No. SP/826

Case #	Title
1	12.5 KW - SEP baseline
2	12.5 KW - 2x2 cells, LMSC substrate
3	12.5 KW - 2x2 cells, GE substrate
4	17.5 KW - 2x4 cells, 75 micron covers, LMSC substrate
5	17.5 KW - 2x2 cells, LMSC substrate
6	17.5 KW - 2x2 cells, GE substrate

System Constants

W = 157.5 inches (panel width)

$L_2/(L_1+L_2) = 0.3$ Panel ratio

L_3 = 10. inches (lower blanket axial offset)

WEND = 18.03 pounds (weight of tip cross member)

BDI: Lower blanket density psf

BDO: Upper blanket density psf

SP2 = 2. pounds pretension

SP3 = 2. pounds pretension

Note: System constants supplied by G. J. Antonides 0/62-25

	Case #					
	1	2	3	4	5	6
L_1+L_2 (in)	1236.	1236.	1236.	1712.	1712.	1712.
BDI	.1946	.1167	.1221	.1787	.1251	.1305
BDO	.1946	.1167	.1221	.1787	.1251	.1305

Boom equations (from automatically deployable able booms, Able Engineering Co.)

Boom weight (pounds)

$$W_I = 9\pi\rho R^2 \varepsilon^2 L = 4.77\times10^{-4} R^2 L$$

π = 3.14159

R: boom radius (inch)

FORM LMSC 3628-3

Prepared by: A. S. Benson	Date 6-30-78	LOCKHEED MISSILES & SPACE COMPANY, INC.	Page 4
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Approved by:	Date		Report No. SP/826

ρ = 0.075 #/in^3
ε = 0.015
L: boom length inches

Boom stiffness

$EI = 1.5\,\pi\, E\, R^4\, \varepsilon^2$

$E = 7.5E6$ #/in^2

Case #	R In	EI # In^2	W_B #	Preload SP1 #
1	7.0	1.9093E7	29.1	8.
2	7.0	1.9093E7	29.1	2.
3	7.0	1.9093E7	29.1	2.
4	9.5	6.4771E7	74.2	16.
5	8.5	4.1511E7	59.4	19.
6	9.0	5.2174E7	66.6	10.

In addition to this information, the fundamental frequency for the 6 cases was requested for the following parameters:

SP1 = 17. pounds
EI = 19.3E6 (R = 7.0189 inches)
(W_B = 29.3 pounds)

Case #1 .0431 hz
Case #2 .0532 hz
Case #3 .0522 hz
Case #4 .0235 hz
Case #5 .0271 hz
Case #6 .0267 hz

FORM LMSC 362B-3